The Distance of the Soft Gamma Repeater SGR 1806–20

Share Your Story

THE DISTANCE OF THE SOFT GAMMA REPEATER SGR 1806−20

S. CORBEL,[1,2] P. WALLYN,[3] T. M. DAME,[4] P. DUROUCHOUX,[2] W. A. MAHONEY,[3]
O. VILHU,[5] AND J. E. GRINDLAY[4]

ABSTRACT

We present ^{12}CO ($J = 1$–0) observations in the direction of the soft gamma repeater SGR 1806−20 with the SEST telescope. We detected several molecular clouds, and we discuss in this paper the implications of these observations for the distance to the X-ray counterpart AX 1805.7−2025, the supernova remnant G10.0−0.3 and the very luminous O9–B2 star detected in the line of sight. The distance of SGR 1806−20 is estimated to be 14.5 ± 1.4 kpc and this soft gamma repeater is very likely associated with one of the brightest H II regions in the Galaxy, W31. The large size of G10.0−0.3 (25×38 pc) for a young supernova remnant possibly powered by a central pulsar (AX 1805.7−2025) indicates that G10.0−0.3 could be expanding in the very low density region produced by the wind of the blue star.
Subject headings: gamma rays: bursts — H II regions — ISM: individual (W31, G10.0−0.3) — stars: individual (SGR 1806−20)

1. INTRODUCTION

Soft gamma repeaters (SGRs) (Norris, Hertz, & Wood 1991) are believed to be a new class of high-energy transients that present recurrent outbursts with shorter duration and softer gamma-ray spectra than gamma-ray bursts (GRBs). Three SGRs have so far been detected, and they seem associated with supernova remnants (SNRs) although SGR 1806−20 is the only source whose position is known with high accuracy. Indeed, one of its bursts has been simultaneously detected by the X-ray satellite *ASCA* (Murakami et al. 1994) and the Burst and Transient Sources Experiment (BATSE) aboard the *Compton Gamma Ray Observatory* (*CGRO*) (Kouveliotou et al. 1994); its position coincides with those of the radio core of the supernova remnant (SNR) G10.0−0.3 (Kulkarni et al. 1994; Vasisht et al. 1995) and a new quiescent X-ray source: AX 1805.7−2025 (Murakami et al. 1994; Sonobe et al. 1994). SGR 1900+14 (Kouveliotou et al. 1993), the other SGR in the Galactic plane, lies near the SNR G42.8+0.6 (Vasisht et al. 1994), but we cannot rule out an association with the superluminal source GRS 1915+105 (Mirabel & Rodríguez 1995). We note that the gamma-ray error box for SGR 0526−66 lies entirely within the SNR N49 in the Large Magellanic Cloud (Cline et al. 1982), although the 1979 March event from this source was $\sim 10^4$ times more luminous than the two SGRs in the Galactic plane. It is possible that SGRs may be associated with giant molecular clouds (GMCs) (Grindlay 1994).

Here we present the first accurate determination of the distance to a soft gamma repeater: SGR 1806−20. The G10.0−0.3 SNR, surrounding SGR 1806−20, appears to be associated with the H II region W31, which is along the line of sight of this SGR. W31 is in turn associated with a large, well-defined molecular complex. We will present new evidence in support of the far kinematic distance for W31

and its associated giant molecular cloud and discuss the implications for SGR 1806−20.

We first report in § 2 ^{12}CO ($J = 1$–0) observations toward SGR 1806−20 with the Swedish ESO Submillimeter Telescope (SEST) and then present new arguments in § 3 to constrain the distance of W31. A detailed analysis (§ 4) of the kinematics of the molecular clouds in the line of sight leads to a possible connection between SGR 1806−20, the SNR G10.0−0.3, W31, and a very bright blue star recently detected by Kulkarni et al. (1995). Based on this analysis, we conclude that the distance to SGR 1806−20 is 14.5 ± 1.4 kpc; we discuss in § 5 the consequences for the size and surrounding medium of the radio SNR and the luminosity of the blue star. Our conclusions are summarized in § 6.

2. OBSERVATIONS

In 1995 April we conducted millimeter observations with the 15 m SEST telescope situated on La Silla in Chile. In order to study the distribution of the molecular gas along the line of sight, we observed the ^{12}CO ($J = 1$–0) emission at the position of the X-ray counterpart detected with *ASCA* at $\alpha(1950) = 18^{\rm h}05^{\rm m}41^{\rm s}$ and $\delta(1950) = -20°25'07''$ (Murakami et al. 1994). The half-power beamwidth (FWHM) of the telescope at 115 GHz is 45''. The front end was a Schottky receiver with a typical system temperature (including atmosphere) of 700 K. The 1086 MHz bandwidth acousto-optical spectrometer (AOS) was used as the back end, with a resolution of 1.4 MHz, giving a velocity resolution of 2.3 km s^{-1}. The intensity calibration was performed using the chopper-wheel method, and the results are given in terms of the main-beam brightness temperature $T_{\rm mb}$ with an rms noise of 0.1 K (the main-beam efficiency of the SEST at 115 GHz is 0.7). Instrumental baseline structure was removed by position switching.

The ^{12}CO ($J = 1$–0) spectrum shown in Figure 1 is quite complex, with distinct molecular clouds at $V_{\rm LSR} = -16$, 4, 13, 24, 38, 73, and 87 km s^{-1} (hereafter MC -16, MC 4, MC 13, MC 24, MC 38, MC 73, and MC 87, respectively). We also used the Galactic survey of Bitran (1987) to study the structure of the molecular clouds. We discuss below the different arguments that constrain the distance to the molecular clouds along the line of sight and their positions compared to SGR 1806−20.

[1] Space Radiation Laboratory, 220-47, California Institute of Technology, Pasadena, CA 91125; corbel@aegir.caltech.edu.
[2] DAPNIA, Service d'Astrophysique, CE Saclay, 91191 Gif-sur-Yvette Cedex, France.
[3] Jet Propulsion Laboratory, 169-327, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109.
[4] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.
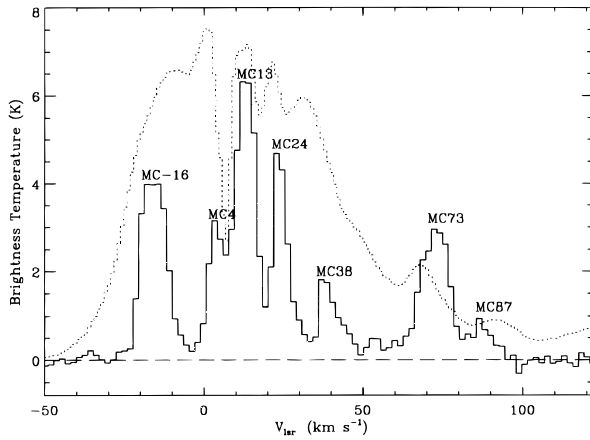[5] Observatory, Box 14, FIN-00014 University of Helsinki, Finland.

FIG. 1.—^{12}CO ($J = 1$–0) spectrum in the direction of SGR 1806−20. The dotted line represents the H I spectrum at $l = 10°$ and $b = -0°.25$ (intensity divided by 14), an average of the spectra at (10, 0) and (10, −0.5) from the Leiden-Dwingeloo survey of neutral hydrogen (Hartmann 1994; Hartmann & Burton 1996).

3. THE DISTANCE TO THE H II COMPLEX W31

W31 is a large and complex H II region located in the Galactic plane around $l = 10°.2$ and $b = -0°.2$. Three components of W31 present a particularly intense radio continuum: G10.2−0.3, G10.3−0.1, and G10.6−0.4. The G10.0−0.3 SNR is also clearly identified with some fainter emission (see Fig. 46 in Shaver & Goss 1970). The closest source to the SNR G10.0−0.3, and by far the brightest in W31, is G10.2−0.3. Observations of the H110α recombination line by Downes et al. (1980) toward G10.2−0.3 showed a peak at a velocity of 13 km s^{-1}. For a more complete review of W31 see Ghosh et al. (1989).

In Figure 2a we present a map of the molecular cloud at 13 km s^{-1} (MC 13) superimposed on the 4.8 GHz radio continuum contour of G10.2−0.3 and G10.3−0.1. The CO ($J = 1$–0) map of MC 13 and the radio continuum contours of W31 seem to be in good agreement with each other. In light of the very close coincidence of MC 13 and W31, both spatially and in velocity, and of the close association of H II
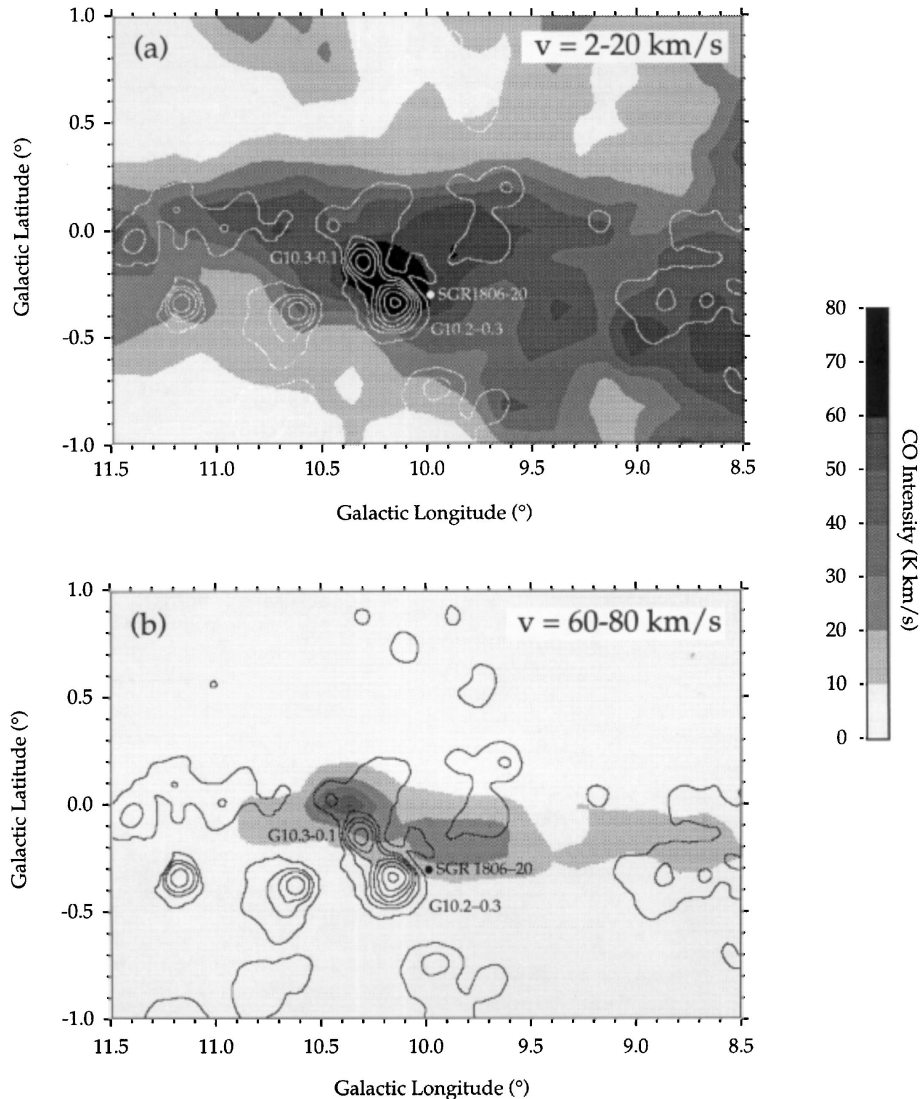

FIG. 2.—(a) ^{12}CO ($J = 1$–0) map of the molecular cloud detected at 13 km s^{-1}. The emission is integrated over the range 2–20 km s^{-1}. The contours at 4850 MHz of G10.2−0.3 and G10.3−0.1 are overplotted (contours at 0.1, 1, 2, 4, 8, 16, 32, 64 Jy beam^{-1}). The dot indicates the position of SGR 1806−20. (b) Same as (a), but for the molecular cloud at 73 km s^{-1}. The CO emission is integrated from 60 to 80 km s^{-1}. These maps are derived from Bitran (1987).

regions with molecular clouds in general, it is very likely that W31 and MC 13 are associated.

With this recombination line at 13 km s^{-1}, and using the Galactic rotation curve of Burton (1988), we deduce a kinematic distance of 2.3 or 14.5 kpc for W31. Moreover, H_2CO, OH, and H I absorption lines against the H II region continuum are detected up to 46 km s^{-1}. Therefore, the H II complex has to be situated behind the clouds detected at the position of the absorption lines. Thus we can rule out the near distance. Based on the lack of H I absorption lines greater than 46 km s^{-1}, it has been argued by Wilson (1974) and Kalberla, Goss, & Wilson (1982) that W31 is not at the far kinematic distance of 14.5 kpc either, but rather in or near the expanding 3 kpc Arm at a distance of ~ 5 kpc. This arm has a large proper motion (expansion velocity of ~ 30 km s^{-1}) compared with the expected V_{LSR} from purely circular Galactic rotation. This became the "standard" distance for W31.

However, absorption at velocities greater than 46 km s^{-1} is *unlikely*, and therefore, there is no reason to reject the far distance. Indeed, at low Galactic longitudes (5°–20°) absorption by H_2CO and cold H I should in general be very rare at velocities greater than 46 km s^{-1} because there is very little gas in any form at such velocities (see, e.g., Fig. 3 in Dame et al. 1987). This "hole" in the gas distribution at $R < 3$ kpc is a well-known feature of the Galaxy (e.g.,

Burton 1976) that was not discussed by Kalberla et al. (1982). One might expect that the cloud we detected at 73 km s^{-1} (this single isolated cloud is visible in the CO longitude-velocity map shown in Fig. 3) would be seen in absorption, but, as Figure 2b shows, the line of sight to G10.2−0.3 (by far the brightest component of W31) passes just *below* the edge of this cloud. The absence of significant CO emission near 73 km s^{-1} toward G10.2−0.3 is confirmed by the higher angular resolution survey of Sanders et al. (1986) (see their b-v map at $l = 10°.2$. Therefore, the lack of absorption against G10.2−0.3 observed by Kalberla et al. (1982) near 73 km s^{-1} is not surprising. It is worth noting that Greisen & Lockman (1979) detected, in a previous observation in the same direction, a weak absorption feature at 75 km s^{-1} in agreement with the position of MC 73 and therefore adopted the far distance for W31. The position we observed (marked "SGR 1806−20" in Fig. 2b) is significantly closer to the center of this cloud, and therefore it is not surprising that we detected it in CO emission. An H_2CO absorption-line measurement at the exact angular position of AX 1805.7−2025 could be very useful to confirm the association of W31 with MC 13, the position of MC 73 relative to W31, and the distance to W31.

Although there is little reason to reject the far distance of 14.5 kpc for MC 13—and in fact we will present evidence below that *favors* it—the anomalous velocity of ~ 30 km
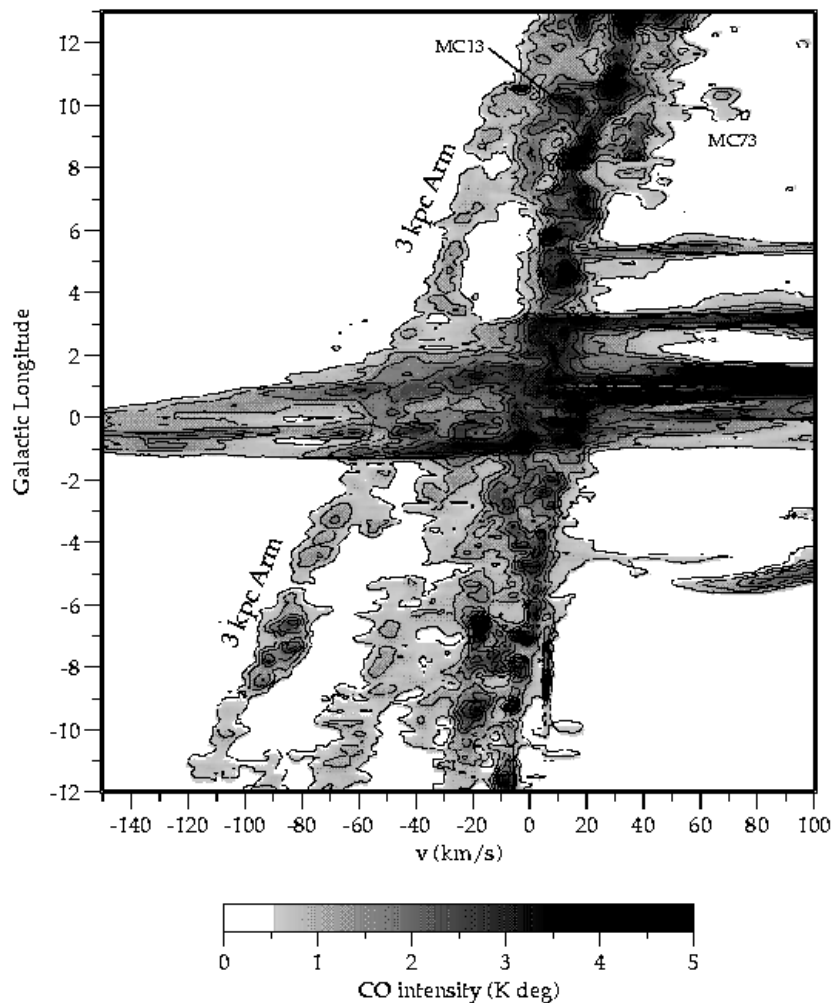

FIG. 3.—Longitude-velocity map of Galactic CO emission integrated in the range from −0°.5 to 0°.5 in latitude from the survey of Bitran (1987). The contour interval is 0.5 K deg.

s^{-1} implied for MC 13 by situating W31 at 5 kpc is very strong evidence *against* it being at that distance. Indeed, it is well established that molecular clouds are a very "cold" Galactic population with a cloud-cloud velocity dispersion of ~ 4.2 km s^{-1} (Combes 1991). Thus, the only plausible way that a large molecular cloud such as MC 13 ($\sim 4 \times 10^5$ $M_\odot$ at a distance of 5 kpc) could have an anomalous velocity of 30 km s^{-1} is if it is associated with the expanding 3 kpc Arm, and that is indeed what Kalberla et al. (1982) and Wilson (1974) suggested.

However, it is very unlikely that MC 13 is associated with the 3 kpc Arm, since (1), as Figure 3 shows, the 3 kpc Arm is a well-defined linear feature in the CO longitude-velocity diagram with a velocity width of only ~ 10 km s^{-1} (and thus a velocity dispersion about the mean, $\sigma_v \leq 5$ km s^{-1}). At $l = 10°$ the arm is centered near -10 km s^{-1}, and so MC 13 lies ~ 23 km s^{-1} ($\sim 5\sigma_v$) outside the central velocity of the arm. (2) The 3 kpc Arm is known to be quite deficient in star formation (Lockman 1989), while W31 is one of the brightest H II regions in the entire Galaxy. (3) As Figure 3 shows, MC 13 is far brighter in CO (and thus far more massive) than any cloud in the 3 kpc Arm.

Additional evidence that MC 13 lies at the far distance of 14.5 kpc comes from comparing its angular size with its line width. It has been well established by many studies that molecular clouds of all sizes exhibit an empirical relation between size and line width (e.g., Dame et al. 1986). It is obvious even from Figure 3 that MC 13 has a small angular size and a large velocity width related to other clouds nearby in the *l-v* map. The large line width implies that the cloud is massive, and the small angular size implies that it is far away. With line width and angular size defined as in Dame et al. (1986), the far distance is clearly favored by the radius–line-width relation ($\Delta V = 16$ km s^{-1}, $R = 63$ pc for a distance of 14.5 kpc). It is worth mentioning that the active star formation indicated by the presence of the very bright W31 H II region and the SNR might be expected to increase the line width of MC 13 somewhat above the normal R-ΔV relation, as observed.

MC 13 is at a sufficiently large Galactic radius (~ 6 kpc) that the Galactic rotation is quite orderly and well measured (Burton 1988). Probably the most significant source of error on the kinematic distance of MC 13 is therefore the cloud-cloud velocity dispersion of molecular clouds (4.2 km s^{-1}; Combes 1991). If we conservatively fold in an additional uncertainty of 10 km s^{-1} due to possible systematic noncircular motions, such as those associated with spiral arms, we obtain a 1 σ error of 1.4 kpc on the far kinematic distance of MC 13. It should be emphasized that uncertainties related to our extinction estimate in § 4.2 (e.g., on

the CO-to-H_2 conversion factor, the gas-to-dust ratio, H I optical depth, etc.) do not have any direct influence on our distance uncertainty, since the distance is determined purely from the cloud's systemic velocity, and this is known to an accuracy of a few kilometers per second. We can therefore conclude that W31 is at the distance of 14.5 ± 1.4 kpc.

4. THE DISTANCE TO SGR 1806−20

4.1. *Position of the Different Molecular Clouds*

We will now discuss the distances to the detected molecular clouds and their positions relative to SGR 1806−20 using our ^{12}CO ($J = 1–0$) spectrum toward AX 1805.7−2025 (Figure 1). The parameters of the clouds are presented in Table 1. In order to study the sizes of the clouds, we used the CO survey of Bitran (1987). The differential Galactic rotation curve (Burton 1988) implies two possible distances for each of the molecular clouds at positive velocity, and one for MC −16. As we showed in § 3, MC 13 is associated with W31 and therefore is at 14.5 kpc. Since W31 and MC 13 are at the far distance, all the clouds at higher velocity (i.e., all except MC 4 and MC −16) must lie in front of them. In the survey of Downes et al. (1980), H_2CO absorption lines against the G10.2−0.3 radio continuum were detected at $V_{LSR} = 1.4, 8.5, 16.6, 26, 32,$ and 36 km s^{-1} (line widths of 6, 7, 4, 3, 3, and 2 km s^{-1}, respectively). The lines at 1.4, 26, and 36 km s^{-1} are compatible with the mean V_{LSR} of the molecular clouds we detected at 4, 24, and 38 km s^{-1} if we take into account the velocity resolution of the AOS and the measured width of the CO lines. These measurements confirm that MC 24 and MC 38 are in front of the W31 complex and imply that MC 4 is located at the near distance of 1 kpc. We have already discussed in § 3 the lack of absorption near 73 km s^{-1}. There is no need to resolve the distance ambiguity for MC 24, MC 38, MC 73, and MC 87, since they are in front of W31 at either distance.

The kinematic distance of the molecular cloud at -16 km s^{-1} (MC -16; FWHM = 10 km s^{-1}) is ~ 22.5 kpc, far outside the orbit of the Sun around the Galactic center. However, an H I absorption feature at $V_{LSR} = -20$ km s^{-1} found in the direction of G10.3−0.1 and G10.2−0.3 (Greisen & Lockman 1979; Kalberla et al. 1982) implies that MC -16 is also in front of W31. To explain both the negative V_{LSR} and a closer distance, MC -16 must have a noncircular motion. As Figure 3 shows, MC -16 lies very close to the 3 kpc Arm. In § 3 we showed that at this Galactic longitude the arm is centered near -10 km s^{-1}, very close to the velocity of MC -16. It is therefore very likely that MC -16 is located in the 3 kpc Arm because (1) an

TABLE 1
DERIVED PARAMETERS FROM THE ^{12}CO ($J = 1–0$) SPECTRUM TOWARD SGR 1806−20

V_{LSR} (km s^{-1})	ΔV(FWHM) (km s^{-1})	Near Distance (kpc)	Far Distance (kpc)	Estimated Distance (kpc)	$N(H_2)$ (10^{21} cm^{-2})	A_V (mag)	ΔA_V (mag)
−16......	10	N.A.	22.5	5.0	8.8	9	2
4..........	5	1.0	16.0	1.0	3.7	4	1
13	7	2.3	14.5	14.5	10.5	11	3
24	5	3.2	13.5	?	6.2	7	2
38	7	4.6	12.3	?	2.9	3	1
73	10	6.2	10.5	?	6.8	7	2
87	6	6.8	10.2	?	1.4	1	0.5

NOTE.—We did not attempt to resolve the distance ambiguity for MC 24, MC 38, MC 73, and MC 87. A_V represents the visual extinction of the cloud, and ΔA_v its uncertainty.

absorption line is detected at -20 km s^{-1}, (2) MC -16 is nearly coincident in velocity with the 3 kpc Arm (1 σ in velocity from the 3 kpc Arm), (3) the angular size of MC -16 implies a diameter of 280 pc at a distance of 22.5 kpc but a much more reasonable diameter of 62 pc at 5 kpc, and (4) molecular clouds beyond the solar orbit are rare. Although the R-ΔV relation ($\Delta V = 18$ km s^{-1}, $R = 31$ pc for a distance of 5 kpc) for normal disk clouds is in favor of the far distance, clouds in the 3 kpc Arm tend to have unusually large line widths (Dame 1996), which may be related to the possibly explosive origin of the 3 kpc Arm or the presence of a bar in the center of our Galaxy. Therefore, MC -16 probably has a proper motion relative to the expected V_{LSR} from a pure Galactic rotation speed, and a distance of ~ 5 kpc is thus deduced. In Figure 4 we present a schematic diagram of the positions of the different molecular clouds.

4.2. SGR 1806$-$20

We now have a better idea of the position of the molecular clouds: MC 13 is associated with W31 at 14.5 kpc, and all the other clouds are closer. To calculate the total H$_2$ column density, $N(H_2)$, due to the molecular clouds detected in the line of sight, we use our ^{12}CO spectrum (Fig. 1) and we use the standard estimate of the ratio (Solomon & Barrett 1991)

$$\frac{N(H_2)}{\int T_{mb}(^{12}CO)dv} = 2 \times 10^{20} \frac{\text{molecules cm}^{-2}}{\text{K km s}^{-1}} . \quad (1)$$

The uncertainty on $N(H_2)$ inferred from this relation is approximately a factor of 2. (W. Langer 1995, private communication). The ^{12}CO ($J = 1$–0) transition is the only line that has been properly calibrated as an H$_2$ mass tracer on a Galactic scale. For estimating H$_2$ column densities across the Galaxy, ^{12}CO is preferable to ^{13}CO (Combes 1991). After doing the ^{12}CO-$N(H_2)$ conversion, it is possible to derive the associated visual extinction, A_V, from the ratio $[N(H\,\textsc{i}) + 2N(H_2)]/E(B-V) = 5.8 \times 10^{21}$ atoms cm^{-2} mag^{-1} (Bohlin, Savage, & Drake 1978) and using $A_V/E(B-V) = 3.1$, also valid at high extinction (Dickman 1978). In a molecular cloud the hydrogen is molecular in

form, so $N(H_2)/A_V = 0.9 \times 10^{21}$ molecules cm^{-2} mag^{-1}. All our results are summarized in Table 1.

Kulkarni et al. (1995) performed visible and near-infrared observations in the direction of SGR 1806$-$20 and revealed the presence of several stars in the X-ray error box of AX 1805.7$-$2025. Among them is a bright blue star (exactly coincident with the core of the G10.0$-$0.3 SNR), possibly a luminous blue variable (LBV), with a high visual extinction ($A_V \sim 30$) in agreement with the ASCA X-ray absorption measurement (Sonobe et al. 1994). Subsequently, van Kerkwijk et al. (1995) obtained near-infrared spectra of this source and detected a He absorption line from which they deduced a spectral type of O9–B2. Even assuming extinction from only MC 73, a molecular cloud quoted in Grindlay (1994) at a distance of 6 kpc, they deduced that this star had to be one of the brightest in our Galaxy with a bolometric luminosity greater than $10^6 L_\odot$.

An X-ray spectrum of AX 1805.7$-$2025 by ASCA gives an absorbing neutral hydrogen column density $N(H) = (6.0 \pm 0.2) \times 10^{22}$ cm^{-2} for a single power-law fit and $N(H) = (5.2 \pm 0.2) \times 10^{22}$ cm^{-2} for a thermal bremsstrahlung model from which a visual extinction of $A_V \sim 30$ is also deduced (Sonobe et al. 1994).

If we integrate all H$_2$ material deduced from CO emissions in front of W31 (this means all the molecular clouds except MC 13), we calculate an extinction of 31 ± 5 mag. We must also consider dust associaated with atomic hydrogen for the origin of the extinction. The 21 cm spectrum in Figure 1 is from the Leiden-Dwingeloo survey of neutral hydrogen (Hartmann 1994; Hartmann & Burton 1996). All the H I emission from $V_{LSR} = 13$ km s^{-1} to infinity can be assumed to arise between us and MC 13, as well as about half the emission in the range 0–13 km s^{-1}. If we make the usual assumption that the H I emission is optically thin, one can deduce the H I column density from the brightness temperature (Burton 1988):

$$N(H\,\textsc{i}) = 1.8 \times 10^{18} \int T_b dv \text{ atoms cm}^{-2} . \quad (2)$$

We estimate 4.5 mag as the contribution from neutral hydrogen to the total extinction in front of W31. Therefore,
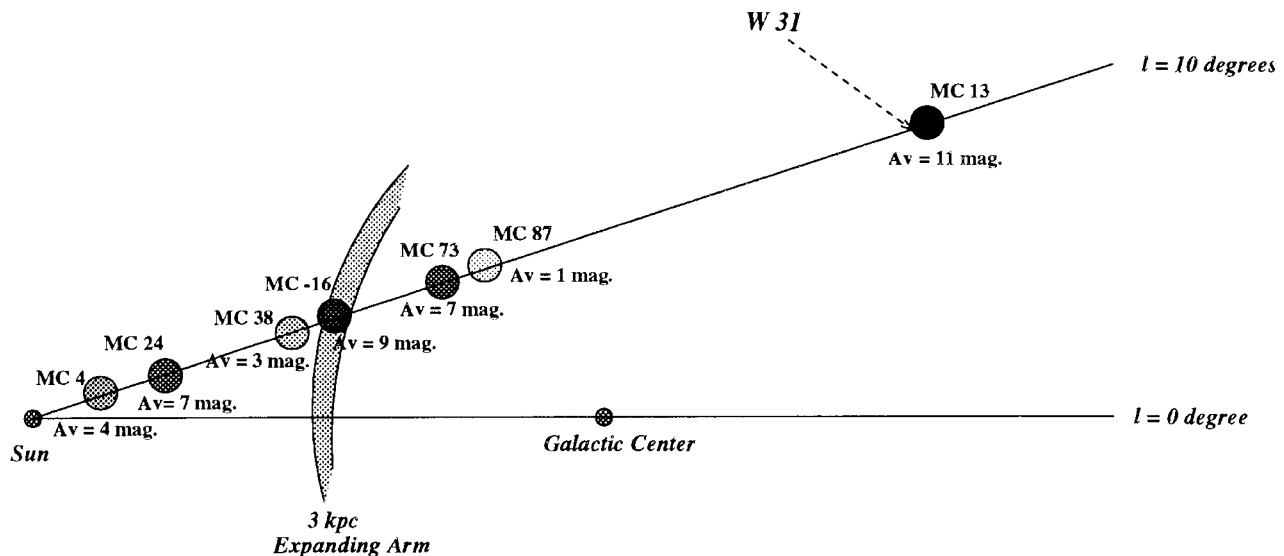

FIG. 4.—Schematic diagram of the molecular clouds in the line of sight of SGR 1806$-$20. The clouds MC 24, MC 38, MC 73, and MC 87 were arbitrarily assigned to their near kinematics distances, but at either distance they lie closer than MC 13. The A_V values represent the visual extinction of the molecular clouds.

we achieve a total visual extinction of 35 ± 5 mag along the line of sight without including MC 13. If we add the contribution of MC 13 ($A_V = 11 \pm 3$ mag), we then have a total extinction of 46 ± 6 mag.

The high intrinsic luminosity of the blue star makes it one of the natural components of the origin of the bright W31 complex, and the massive GMC MC 13 a probable progenitor. Moreover, the total visual extinction favors a position of this O9–B2 star near the front edge of MC 13. AX 1805.7−2025 shows the same extinction as the previous star, and seems to be the core of the G10.0−0.3 SNR, which is therefore also located in W31. It is even possible that part of MC 13 also contributes to the extinction of SGR 1806−20. There is an H_2CO absorption line at 16.6 km s^{-1} ($\Delta V = 4$ km s^{-1}; Downes et al. 1980) detected against the radio continuum of G10.2−0.3, which is compatible with the velocity of MC 13. In Figure 2a the SNR G10.0−0.3 seems to be located on the edge of MC 13 (the position of SGR 1806−20 is the same as the core of G10.0−0.3).

A likely scenario is that W31 is inside MC 13. This massive cloud gives birth to massive stars that create the W31 H II region, and some of these stars burn all their material and become SNRs. W31 would then be embedded inside MC 13 and extend to its edge, where the G10.0−0.3 SNR is located. The star formation continues inside MC 13.

From (1) the spatial coincidence of AX 1805.7−2025 and the LBV star with SGR 1806−20, (2) the probable association of the SNR and the LBV star with W31 and MC 13, (3) the presence of an LBV star with the same absorption as the X-ray counterpart of SGR 1806−20, and (4) the measured absorption of all the material along the line of sight, it is possible to deduce that both SGR 1806−20 and the O9–B2 star probably reside in W31, i.e., on the edge of the giant molecular cloud at $V_{LSR} = 13$ km s^{-1} and thus at the distance of 14.5 ± 1.4 kpc. Let us nevertheless point out that our conclusion is based on the assumption that there is no self-absorption from that source. We discuss below the possible connection between SGR 1806−20 and the O9–B2 star.

5. DISCUSSION

5.1. The Radio Nebula G10.0−0.3

The radio nebula G10.0−0.3 consists of nested shells and a bright central peak. Kulkarni et al. (1994) suggested that it consists of a young isolated pulsar powering a surrounding 9×6 arcmin^2 SNR with relativistic particles. From our distance evaluation, we thus deduce that the SNR has a size of 25×38 pc^2.

Kafatos et al. (1980) studied the interaction between supernova ejecta and their environments. In the rarefied interstellar medium (ISM), after the initial supernova explosion, the ejecta expand freely without bound (free-expansion phase) and then encounter significant gas to form a shock and a shell that is detectable as a radio SNR. For a SNR expanding in the ISM, Wheeler et al. (1980) find a typical SNR radius of ~ 3.1 pc at the end of the free-expansion phase and 0.12 pc for a SNR expanding in a molecular cloud with density $n \sim 10^4$ cm^{-3}. Kulkarni et al. (1994) favor a young pulsar of age less than 10^4 yr at the origin of the steady X-ray source AX 1805.7−2025. Using Table 1 in Kafatos et al. (1980), we found that the size of the SNR of 25×38 pc^2 (radius of ~ 16 pc) and the approximate age of the pulsar favor a third possibility that implies a possible

connection between the O9–B2 star and the SNR: the expansion of the G10.0−0.3 SNR in the hot and highly evacuated volume produced by the wind from the bright O9–B2 star. Indeed, Kafatos et al. (1980) found typical radii of the order of ~ 19 pc at the end of the free-expansion phase (age $< 3.7 \times 10^3$ yr) for a SNR expanding in a very low density region.

5.2. The Luminous Star in the Direction of SGR 1806−20

With our distance evaluation, the O9–B2 star is very luminous, with nearly $\sim 5 \times 10^6$ $L_\odot$, and is perhaps the brightest star in the Galaxy. It is of course still not clear what is the physical connection of this LBV star and the SGR source, although the extreme luminosity suggests an association. We note that several stars not resolved by the telescope could produce the same result. High-resolution infrared observations of this star should be very useful to solve the problem. If the "LBV star" is actually a cluster, this might also be instead hot gas and wind heated by accretion onto a single massive object in the GMC, as suggested in Grindlay (1994) for SGR sources in general.

6. CONCLUSIONS

By studying the kinematics of the molecular clouds along the line of sight to W31, we draw the conclusion that this H II complex is located at the far kinematic distance of 14.5 ± 1.4 kpc. This H II region is probably created inside the giant molecular cloud detected at 13 km s^{-1} (MC 13). At the far distance, MC 13 is one of the most massive molecular complexes in the Galaxy ($\sim 4 \times 10^6$ $M_\odot$). It is not surprising that such a cloud would be associated with one of the Galaxy's brightest H II regions, and one of its brightest stars (or compact clusters).

Based on the apparent association of SGR 1806−20, the SNR G10.0−0.3, the H II region W31, and the GMC at 13 km s^{-1}, it was possible to constrain the distance to SGR 1806−20 to 14.5 ± 1.4 kpc with some confidence. The derived extinction deduced from CO and H I observations is consistent with that distance. It is even possible that the G10.0−0.3 SNR expands into the windswept region from the O9–B2 star.

Scheduled millimeter observations of molecules with enhanced abundances in high-ionization environments such as HCO$^+$, HCN, and CN (Durouchoux et al. 1997), or the study of shock tracers such as the IR transition at 1.58 μm of C$^+$ (S. Kulkarni 1995, private communication) could be very useful to confirm the association of the SNR with MC 13. Continuum measurements at $\lambda = 1$–3 mm of the thermal emission from dust and *IRAS* high-resolution maps have been published elsewhere (Wallyn et al. 1995; Smith et al. 1996; van Paradijs et al. 1996). Our results agree with the scenario of a young neutron star in a SNR for SGR 1806−20, but the mechanism at the origin of the short X-ray bursts detected remains unclear. The accurate distance evaluation of SGR 1806−20 could yield new constraints on SGR emission theories (e.g., Ulmer 1994; Baring 1995; Melia & Fatuzzo 1995; Duncan & Thompson 1996; Thompson & Duncan 1995).

Note added in manuscript.—We recently observed the 23.694 GHz line of the NH$_3$ transition against the radio continuum of the core of the G10.0−0.3 SNR, and we detected an absorption line at a velocity of 73 km s^{-1}. This detection confirms that the SNR and its associated molecu-

CORBEL ET AL.

lar cloud MC 13 lie behind MC 73 and therefore must be at the far kinematic distance, as we proposed.

REFERENCES

Baring, M. G. 1995, ApJ, 440, L69
Bitran, M. E. 1987, Ph.D. thesis, Univ. Florida
Bohlin, R. C., Savage, B. D., & Drake, J. F. 1978, ApJ, 224, 132
Burton, W. B. 1976, ARA&A, 14, 275
———. 1988, in Galactic and Extra-Galactic Radio Astronomy, ed. G. L. Verschuur & K. I. Kellermann (Berlin: Springer), 295
Cline, T. L., et al. 1982, ApJ, 255, L45
Combes, F. 1991, ARA&A, 29, 145
Dame, T. M. 1996, private communication
Dame, T. M., Elmegreen, B. G., Cohen, R. S., & Thaddeus, P. 1986, ApJ, 305, 892
Dame, T. M., et al. 1987, ApJ, 322, 706
Dickman, R. L. 1978, ApJS, 37, 407
Downes, D., Wilson, T. L., Bieging, J., & Wink, J. 1980, A&AS, 40, 379
Duncan, R. C., & Thompson, C. 1996, in High Velocity Neutron Stars and Gamma-Rays, ed. R. E. Rothschild et al. (New York: AIP), in press
Durouchoux, P., et al. 1997, in preparation
Ghosh, S. K., Iyengar, K. V. K., Rengarajan, T. N., Tandon, S. N., Verna, R. P., & Daniel, R. R. 1989, ApJ, 347, 338
Greisen, E., & Lockman, F. J. 1979, ApJ, 228, 740
Grindlay, J. E. 1994, ApJS, 92, 465
Hartmann, D. 1994, Ph.D. thesis, Univ. Leiden
Hartmann, D., & Burton, W. B. 1996, Atlas of Galactic H I Emission (Cambridge: Cambridge Univ. Press), in press
Kafatos, M., Sofia, S., Bruhweiler, F., & Gull, T. 1980, ApJ, 242, 294
Kalberla, P. M. W., Goss, W. M., & Wilson, T. L. 1982, A&A, 106, 167
Kouveliotou, C., et al. 1993, Nature, 362, 728
———. 1994, Nature, 368, 125
Kulkarni, S. R., Frail, D. A., Kassim, N. E., Murakami, T., & Vasisht, G. 1994, Nature, 368, 129
Kulkarni, S. R., Matthews, K., Neugebauer, G., Reid, I. N., van Kerkwijk, M. H., & Vasisht, G. 1995, ApJ, 440, L61
Lockman, F. J. 1989, ApJS, 71, 469
Melia, F., & Fatuzzo, M. 1995, ApJ, 438, 904
Mirabel, I. F., & Rodríguez, L. F. 1995, Ap&SS, 231, 65
Murakami, T., et al. 1994, Nature, 368, 127
Norris, J. P., Hertz, P., & Wood, K. S. 1991, ApJ, 366, 240
Sanders, D. B., Clemens, D. P., Scoville, N. Z., & Solomon, P. M. 1986, ApJS, 60, 1
Shaver, P. A., & Goss, W. M. 1970, Australian J. Phys., Astrophys. Suppl., 14, 77
Smith, I. A., et al. 1996, in High Velocity Neutron Stars and Gamma-Rays, ed. R. E. Rothschild et al. (New York: AIP), in press
Solomon, P. M., & Barrett, J. W. 1991, in IAU Symp. 146, Dynamics of Galaxies and Their Molecular Cloud Distributions, ed. F. Combes & F. Casoli (Dordrecht: Kluwer), 235
Sonobe, T., Murakami, T., Kulkarni, S. R., Aoki, T., & Yoshida, A. 1994, ApJ, 436, L23
Thompson, C., & Duncan, R. C. 1995, MNRAS, 275, 255
Ulmer, A. 1994, ApJ, 437, L111
van Kerkwijk, M. H., Kulkarni, S. R., Matthews, K., & Neugebauer, G. 1995, ApJ, 444, L33
van Paradijs, J., et al. 1996, A&A, in press
Vasisht, G., Kulkarni, S. R., Frail, D. A., & Greiner, J. 1994, ApJ, 431, L35
Vasisht, G., Frail, D. A., & Kulkarni, S. R. 1995, ApJ, 440, L65
Wallyn, P., Mahoney, W. A., Corbel, S., Cao, Y., Durouchoux, P., & Vilhu, V. 1995, Ap&SS, 231, 89
Wheeler, J. C., Mazurek, T. J., & Sivaramakrishnam, A. 1980, ApJ, 237, 781
Wilson, T. L. 1974, A&A, 31, 83